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Guide to Drying Defects:

A Supplement to the Drying Quality Assessment

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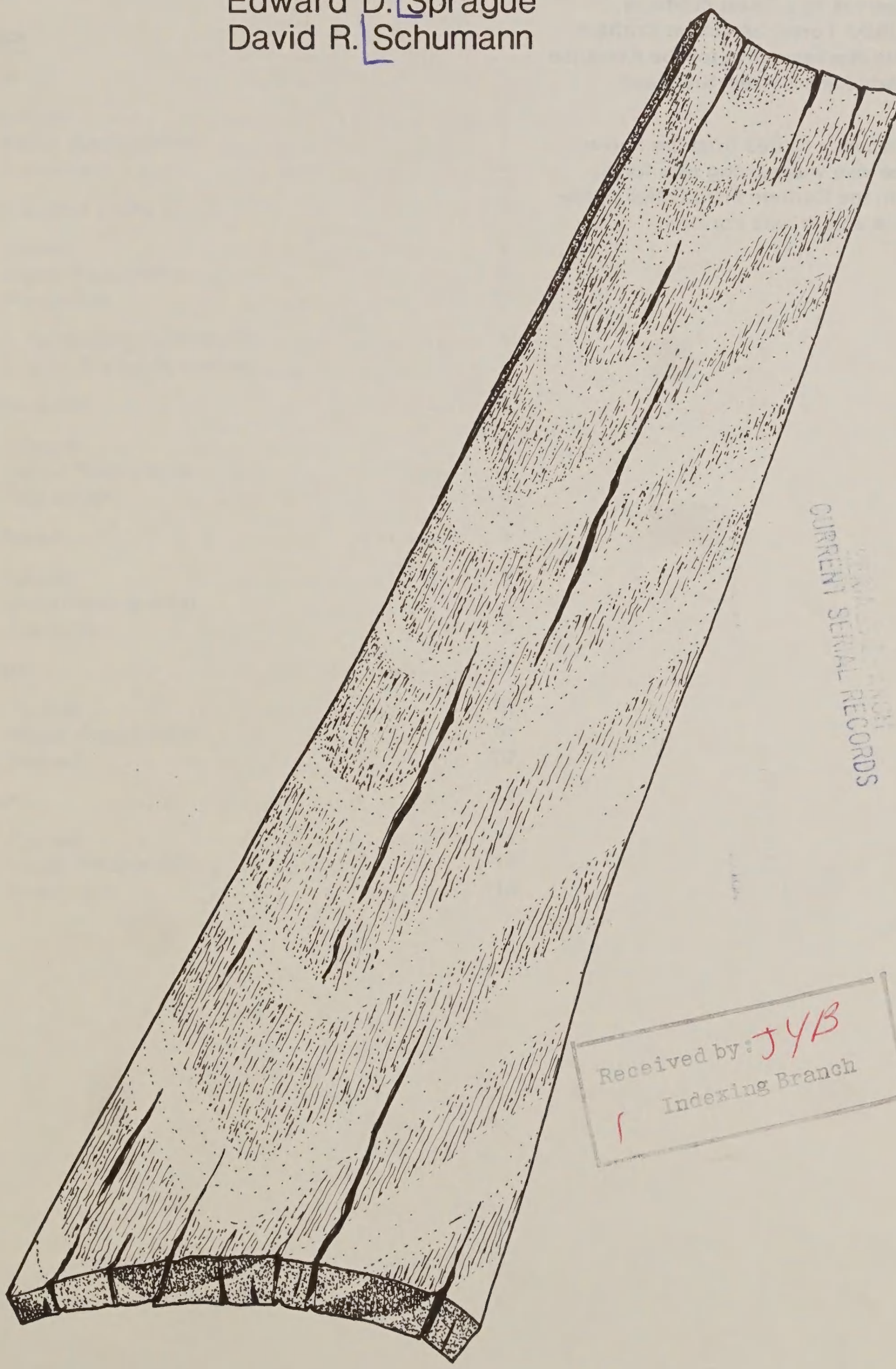

The Authors

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Guide to Drying Defects
A Supplement to the Drying Quality Assessment

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Introduction

The "Drying Quality Assessment" (DQA) is a computer program designed to determine losses in yields due to the various types of drying degrade. It stimulates a roughmill operation by sawing a given board into given cutting sizes, tallying the number of cuttings made in each size, and determines the percentage yield for each board. It then systematically eliminates the different types of drying degrade and "recuts" the board. Each individual board is "cut" eight times, each time with a different drying degrade scheme, to provide a basis for comparison of the effects of different types of drying degrade upon yield.

DQA was developed under a cooperative agreement between USDA Forest Service, NA-S&PF and Virginia Polytechnic Institute and State University. Assistance in applying the program is available from the School of Forest Products, VPI, Blacksburg, VA.

This Supplement is prepared to aid in recognizing drying defect and implementing change once the drying quality losses have been quantified. It is limited to identifying and measuring the extent of cup, bow, crook, surface checks, splits, and end checks, but such things as honeycomb, collapse, stress, and stain are included so the user can recognize and cope with them. A drying defect may result from the interaction of a number of poor practices; therefore one remedy may not eliminate the entire problem. Judgement is needed to determine what steps should be taken to reduce drying defects cheaply. After a change is made, DQA can be applied again to determine the cost-effectiveness of the action.

I. Warp

A. Causes

Warp is any variation from a true or plane surface. It includes bow, crook, cup, twist, and combinations of these, as well as diamonding in squares or out-of-round in turnings (Fig. 1). Warp is the product of shrinkage in drying or the relief of growth and drying stresses, particularly around knots, spiral grain, diagonal grain, juvenile wood, and reaction wood. It can be accentuated by the ratio of heartwood to sapwood within a given board, uneven or off-center boards in a lumber stack, and uneven moisture content distribution within a given board.

B. Visual Recognition

Bow is distortion of a board that deviates from flatness lengthwise, but not across its face. Bow is frequently induced by poor stacking, thick and thin sawn lumber, or both (Fig. 1).

Crook is distortion in a board in which there is a deviation edgewise from a straight line from end to end (Fig. 1).

Cup is distortion of a board in which there is deviation from flatness across the width of the board (Fig. 1).

Twist is distortion in a board such that four corners of any face are no longer in the same plane (Fig. 1).

Knots are evidence of limbs in the standing tree. In a board, they represent a zone of end grain exhibiting both radial and tangential shrinkage. Wood surrounding the knot is usually distorted and has "local slope of grain." Drying this wood results in crook and bow, and loosening, falling-out, or checking of the knots.

Spiral grain in the tree is the result of fiber growing in a winding or spiral pattern instead of vertically. In sawn products, spiral grain fibers lie in the tangential plane of growth rings, not parallel to the longitudinal axis of the product (Figure 2b,d,f,h). Spiral grain is not always easy to detect in sawn products; it may reveal itself when surface checks develop on drying as they follow the direction of fibers on the flat-sawn face. Another way to detect it is to split the piece and observe the grain direction.

Diagonal grain is cross-grain caused by growth rings not parallel to one or both surfaces of a sawn piece. It is produced by sawing boards parallel to the pith from logs with pronounced taper, a common occurrence in sawing crooked or swelled logs (Figure 2c,d,g,h). Where the grain runs out on the flat-sawn faces, checks and splits will develop as in other end grain, and cup, bow, and crook will be pronounced.

Juvenile wood is the growth near the pith of a tree, and is characterized by indistinct growth rings and excessive shrinkage along the longitudinal axis.

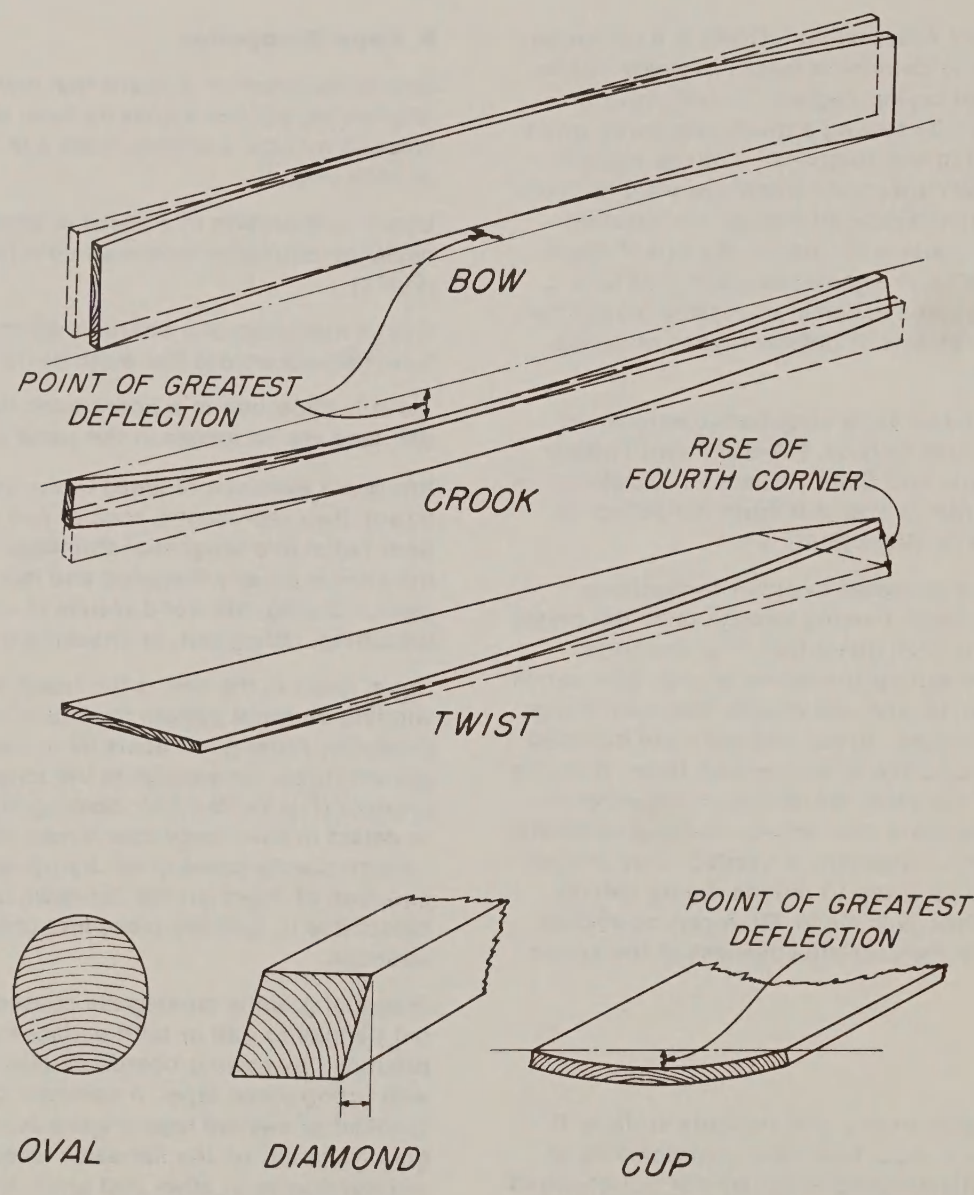

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Figure 1.—Various types of warp in lumber. USDA For. Serv., Agric. Handb. 528.

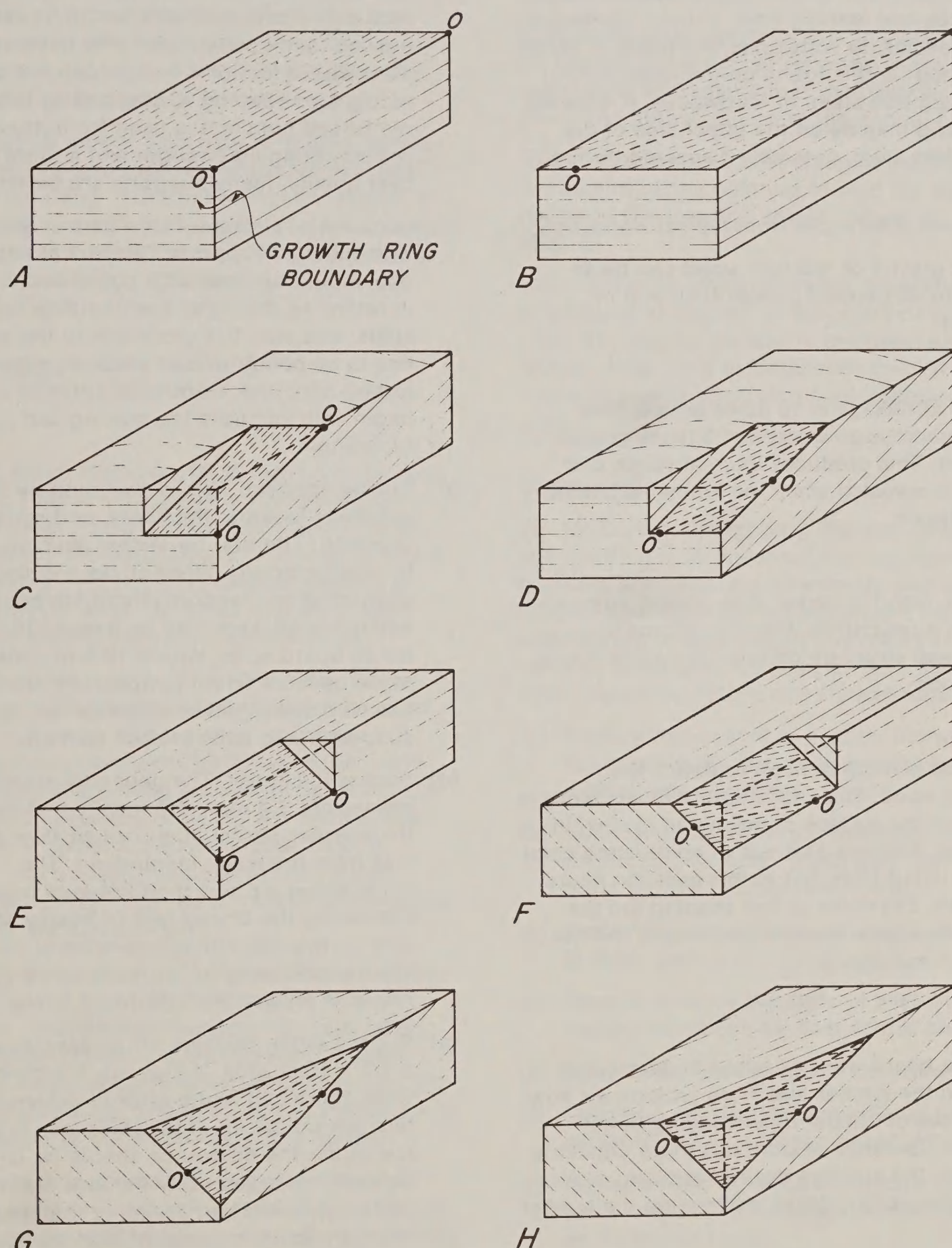

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Figure 2.—Schematic views of wood specimens containing straight grain and cross grain to illustrate the relationship of fiber orientation (0-0) to the axis of the piece. Specimens A through D have radial and tangential surfaces; E through H do not. A and E contain no cross grain. B, D, F, and H have spiral grain. C, D, G, and H have diagonal grain. USDA For. Serv., Agric. Handb. 72.

Reaction wood is aberrant tissue, frequently associated with crooked limbs and leaning trees of both coniferous and deciduous species. In softwoods, the tissue is called "compression wood" and is found on the lower side of the limb or inclined tree stem. In hardwoods, it is called "tension wood" and may be on the upper side of the limb or inclined tree stem, or widely dispersed throughout the bole.

Some of its distinct differences from typical wood are:

(1) The specific gravity of reaction wood can be as much as 30 to 40 percent greater than that of normal wood.

(2) Longitudinal shrinkage is 10 times greater than normal in compression wood and 5 times greater in tension wood. This produces internal stress and warp which is revealed when the lumber is planed, ripped, or resawn.

(3) Compression wood is darker than normal summerwood, which it resembles. Electron microscopy reveals cell wall structure different from that found in normal wood.

(4) Tension wood is more difficult to detect than compression wood. One indication of its presence is uncut fiber on the surface of machined pieces. In some species, it shows as areas of contrasting color. This, too, is uncut fiber, but in this case the fibers are very short. Examples of this shading are the silvery surface appearance in hard maple and the dark zones in mahogany.

C. Prevention

Steps to minimize board warp all relate to developing better restraint on the lumber and more uniform air flow through the courses of lumber by employing better stacking practices. Because of cost, it is more critical to control warp when the cuttings desired are long or wide. The elements in developing good restraint on the lumber are:

(1) Supports and stickers

(a) Load supports. The thinner the lumber being stacked, the greater the number of load supports needed. The generally accepted practice for 4/4 hardwood is to place bolsters on 2 foot centers or less with a minimum of 1 foot. The same practice applies to 4/4 softwoods to be used in furniture, otherwise 3 feet or 4 feet on centers is the recognized spacing. Occasionally, thick dunnage or reinforced concrete is used for bottom courses to provide bridging strength and a more rigid base. For best quality, many supports are better than too few.

(b) Location of stickers. Place tiers of stickers in line with the load supports. Stickers at each end of the pile should be flush with board ends to be effective in retarding drying and minimizing end checks, splits, and cup, but closeness to the end sometimes has to be compromised because sticks fall out in forklift handling. Control to optimize yield has to begin with accurate log making and lumber end trimming.

(c) Sticker spacing. This is governed by the stock's tendency to warp, thickness, and resistance to crushing. The rule for sticker spacing is the same as for load supports, since sticks and supports must be aligned. When random length lumber is box-piled, additional stickers may be needed to assure support for all board ends. Where 16 foot packages are made up from 8 foot lumber, two stickers should be placed close together at the center of the load to support board ends in each section.

(d) Sticker thickness. The generally accepted thicknesses are 3/4 inch, 7/8 inch, and 1 inch. These thicknesses permit adequate air flow and minimize loss from breakage in handling. The 1 inch stickers allow better air flow than 3/4-inch ones, effectively increasing the drying rate of freshly sawn lumber. The normal machining tolerance of ±0.010" should assure uniformity in course spacing and good restraint on well manufactured lumber.

(e) Sticker width. Stickers for all species should be 1 to 1-1/2 inches wide. If they are 1 inch thick and 1 inch wide, there can be no error in determining which face should be up. If the thickness is different from the width, the difference should be large enough to be easily recognized by persons stacking lumber. Wide stickers retard drying in the area they cover, and can result in zones of high moisture content in the lumber at the end of the drying cycle.

(2) Weights

Weight on top of lumber stacks reduces the amount of warp, especially in the top courses, if proper piling

procedures have been used and the lumber is sawn to uniform thickness. A sound decision on whether to employ weight can be reached by using the *Drying Quality Assessment* exercise to determine the volume and value of cuttings that can be recovered.

The simplest way to weight packages is to load pallets with concrete blocks or design a reenforced concrete slab for forklift handling. If metal fasteners are used, as they are in pallets, and oak is being dried, do not allow the nail heads to contact the lumber. They will leave a black stain. To be effective, a minimum of 200 lb per square foot is needed.

II. Checks and Splits

A. Causes

Surface checks result from normal stresses that develop in drying wood. They are fractures in the wood rays and their severity is determined by how warm and how wet the lumber is during the early stages of drying. Wood is strongest when it is cool and dry; weakest when it is warm and wet. Thick, wide, flat-sawn lumber is more prone to surface checks than thin, narrow stock.

Surface checks usually close at the end of the drying process and become impossible to see with the naked eye. This does not mean that they are no longer significant. They are permanent fractures in the wood surface, and any that are deep enough to penetrate the surface removed in machine dressing will appear when finish is applied. In products such as bowling pins, tennis rackets, tool handles, and certain structural members, surface checks opened or closed will increase the tendency for the piece to split.

End Checks. These are fractures of wood rays, just like surface checking and for the same reasons, with an additional factor: Wood loses moisture 10 times faster through the end grain than it does through the face grain; therefore, stresses build faster. End checking will precede surface checking. The tendency to end check is also directly related to the thickness of the lumber.

End Splits. These defects are the extensions of end checks. In assessing drying quality, it should be kept in mind that the end defects may have developed in the log in the woods, in transit, or in storage at the mill, on or off sticks. Sometimes, examining the inside of a check or split with a 10X hand lens will reveal dirt particles to indicate that the defect developed in one of these locations rather than in the dry kiln.

B. Visual Recognition

Surface checks appear as fine to coarse splits in the surface of a board or other wood product. The identifying characteristic is that they run parallel to the grain and perpendicular to the annual rings (Fig. 3).

End checks originate on end grain surfaces and appear as radiating lines pointing toward the pith or heart center of the tree and at right angles to the annual rings (Fig. 4).

Splits are longitudinal or radial separations of the wood, originating at the end of the board or other wood product, running parallel to the grain and across the annual rings. This distinguishes them from "shake," which is a separation within and parallel to the annual ring.

C. Prevention

(1) Air Drying Operations. The way to control checking and splitting is to dry slowly by raising the relative humidity and lowering air velocity and temperature. The following air drying practices should be considered when trying to accomplish this objective. The economic value of these practices can be determined by using a *DQA technique* before and after change.

(a) Employ pile covers to prevent too rapid drying of top courses, as well as to protect dry stock from wetting and rewetting.

(b) Employ wind baffles to control air flow through piles or across pile ends. These may take the form of walls, panels, burlap covers, etc.

(c) Place refractory species, such as beech and oak, on the leeward side of the yard.

(d) Stagger piles so the ends of piles in adjacent rows overlap to reduce air flow across pile ends.

(e) Build wider piles to retard moisture loss.

(f) Surround species that are difficult to dry with species easier to dry as a means of reducing air flow.

(g) Use end coating on 6/4 and thicker stock, especially in short lengths. To be effective, the coating must be put on freshly cut ends.

Figure 3.—Boards with surface checks and splits. USDA For. Serv., Agric. Handb. 402.

Figure 4.—Boards with end splits. USDA For. Serv., Agric. Handb. 402.

(2) Kiln Drying Operations. The key to preventing checks and splits in kiln drying green stock is to use low temperature to minimize the likelihood of building in stress that exceeds the ray strength of the wood. Other factors to consider:

(a) End coat 6/4 and thicker stock, especially short lengths. To be effective, the coating must be put on freshly cut ends.

(b) Pay particular attention to baffling air flow to eliminate zones of high velocity around package ends, bunker openings, and over the tops of kiln loads.

(c) Place stickers to conform to good practice, to achieve uniform air flow through the lumber.

(d) Use kiln loading practices that provide uniform air flow through the packages. This is very important in the package-loaded kiln.

(e) Consult the kiln manufacturer if lumber in the center of the kiln has more defect than lumber to the outside. The air across the load may reach saturation too soon; this can be a function of kiln design.

(f) Calibrate wet and dry bulb properly. If this is not done, conditions in the kiln may be far more severe than those indicated on the controller-recorder.

(g) Make sure that the air to operate the recorder-controller is clean and at the correct pressure.

(h) See that all fans operate properly.

(i) Check that the steam system functions properly. Inspect for local cold spots. If the recorder-controller dry bulb fluctuates extremely, there may be too much radiation and some coils should be shut off. *DQA* can be useful in analyzing the differences in degrade development top to bottom and side to center, within a given kiln.

III. Honeycomb

A. Causes

Honeycomb is an internal void, an interior fracture along the wood ray, which is not visible from the surface. Usually these fractures are first noticed when the wood is opened up in the machining process.

Deep surface and end checks that have closed tightly on the surface of the stock but remain as interor voids are designated as honeycomb, too. They also may be referred to as bottleneck checks.

Honeycomb is produced by temperature that is too high in the period when there is free water in the cell cavities. The wood may not fail until midway in the drying process, or later, depending upon stress development.

B. Visual Recognition

Honeycomb and collapse are frequently associated. When the stock surface has a corrugated appearance, as in collapse, honeycomb can be suspected (Fig. 5 and 6).

C. Prevention

(1) Avoid high dry bulb temperatures until all free water has been removed from refractory species of lumber, each piece throughout its length.

(2) Avoid driving checks deeper in surface-checked lumber by moderating the severity of the drying conditions.

(3) Avoid letting lumber with less than 20 percent moisture content regain moisture content rapidly.

(4) Prevent end checks from penetrating to become interior voids by protecting the ends and providing good air circulation over the lumber faces.

IV. Collapse

A. Causes

Collapse is the flattening of single cells or rows of cells in heartwood during the drying or pressure treatment of wood.

Collapse may be caused by: compressive drying stresses on the interior parts of the wood that exceed the compressive strength of the wood cells or liquid tension in cell cavities that are completely filled with water. Both conditions occur early in the drying process and are associated with excessive dry-bulb temperatures.

B. Visual Recognition

Collapse is usually not visible on the wood surface until midway or in the drying process, or later though weakening of the wall structure takes place early. When visible, it has a characteristic caved-in or corrugated appearance (Fig. 6).

C. Prevention

Avoid excessive dry-bulb temperatures in the early stages of drying.

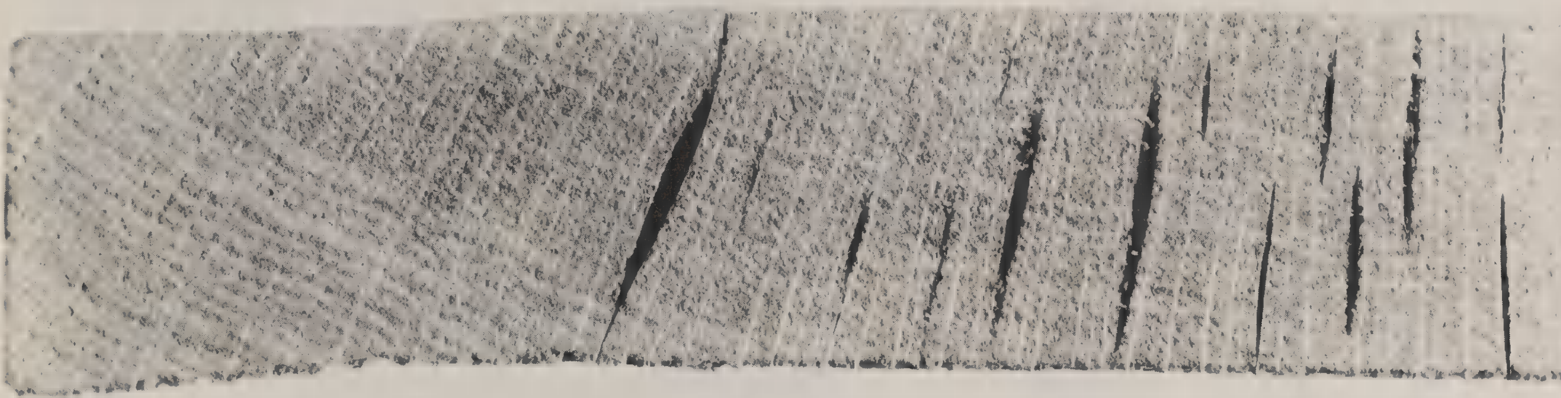

Figure 5.—Honeycomb: the product of exposure to high temperature while free water is still in cell cavities. USDA For. Serv., Agric. Handb. 188.

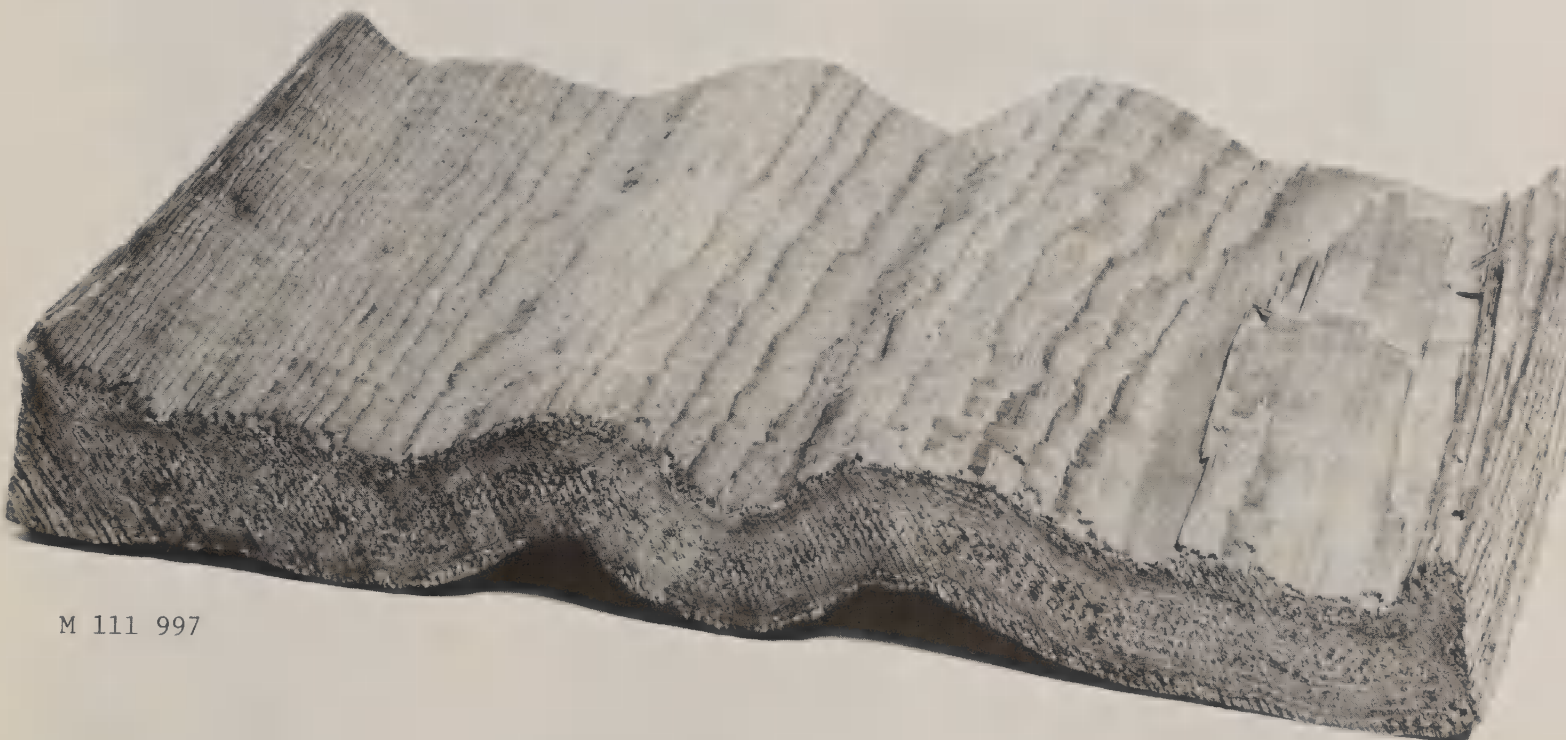

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Figure 6.—An example of collapse, the result of excessive temperature while free water is still present in cell cavities. USDA For. Serv., Agric. Handb. 188.

V. Stress

A. Causes

Stress is a normal response in wood dried by conventional kiln drying processes. It is an internal force, exerted by either of two adjacent parts of a piece of wood upon the other during drying, caused by uneven drying and shrinking, and influenced by "set." Set is a localized semipermanent deformation caused by internal tensile or compressive stresses.

B. Visual Recognition

The accepted way to determine the amount of stress in lumber is to make prong tests. There are two: one is crosssectional (transverse), the other longitudinal (Fig. 7). Prongs that pinch in, indicate stress. If they stand erect or spread slightly outward, stress has been relieved.

It should be noted that stress relief is not always needed. The degree of stress that can be permitted relates to the end product (see Item C).

Stress in individual pieces may reveal itself as immediate warp. In resawing, the wood may cup, with the concave faces toward the saw (Fig. 8). In ripsawing, crook may result, with the concave edges usually on the saw cut side. Splitting may occur on surface planing. In 2-sided planing, the depth of the cuts may differ. If the board has stress, it will cup and the concave face will be toward the side with the heaviest cut.

In edgegrooved, casehardened stock the lips of the groove will pinch inward (Fig. 7). A tongue or spline inserted into such a groove may break the lips.

In molding, routing and carving unequal cuts may be taken from the faces and edges, with resultant cup and bow.

The key point in recognizing the influence of stress in wood is that the distortion will occur immediately as the piece leaves the machining operation. If there is a time delay, the problem is related to moisture content rather than stress.

C. Remedy

Make a practice of finishing off kiln charges with a conditioning cycle, unless it is known that stress in the lumber is no problem in the end product. Conditioning is strongly recommended for lumber that is to be used in furniture, architectural millwork, sash and door stock, and any products that require sawing and planing operations that unbalance the stresses. The procedure for conditioning a kiln charge of lumber is as follows:

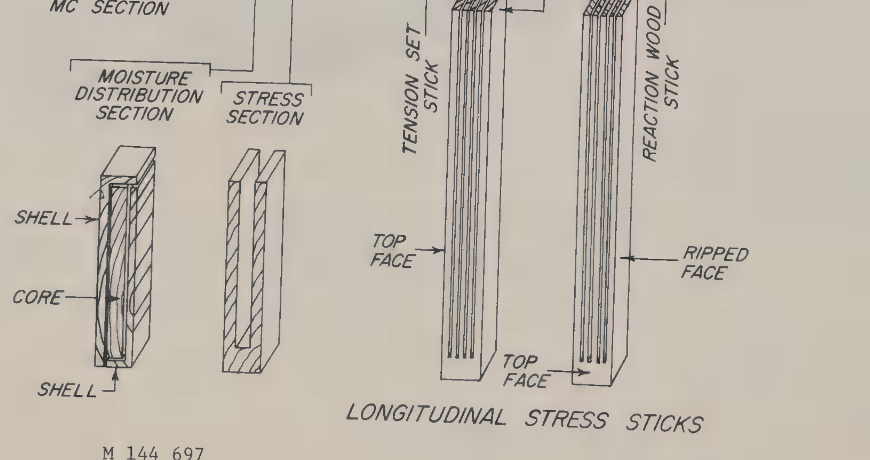

Figure 7.—Final moisture content and stress tests. USDA For. Serv., Agric. Handb. 528.

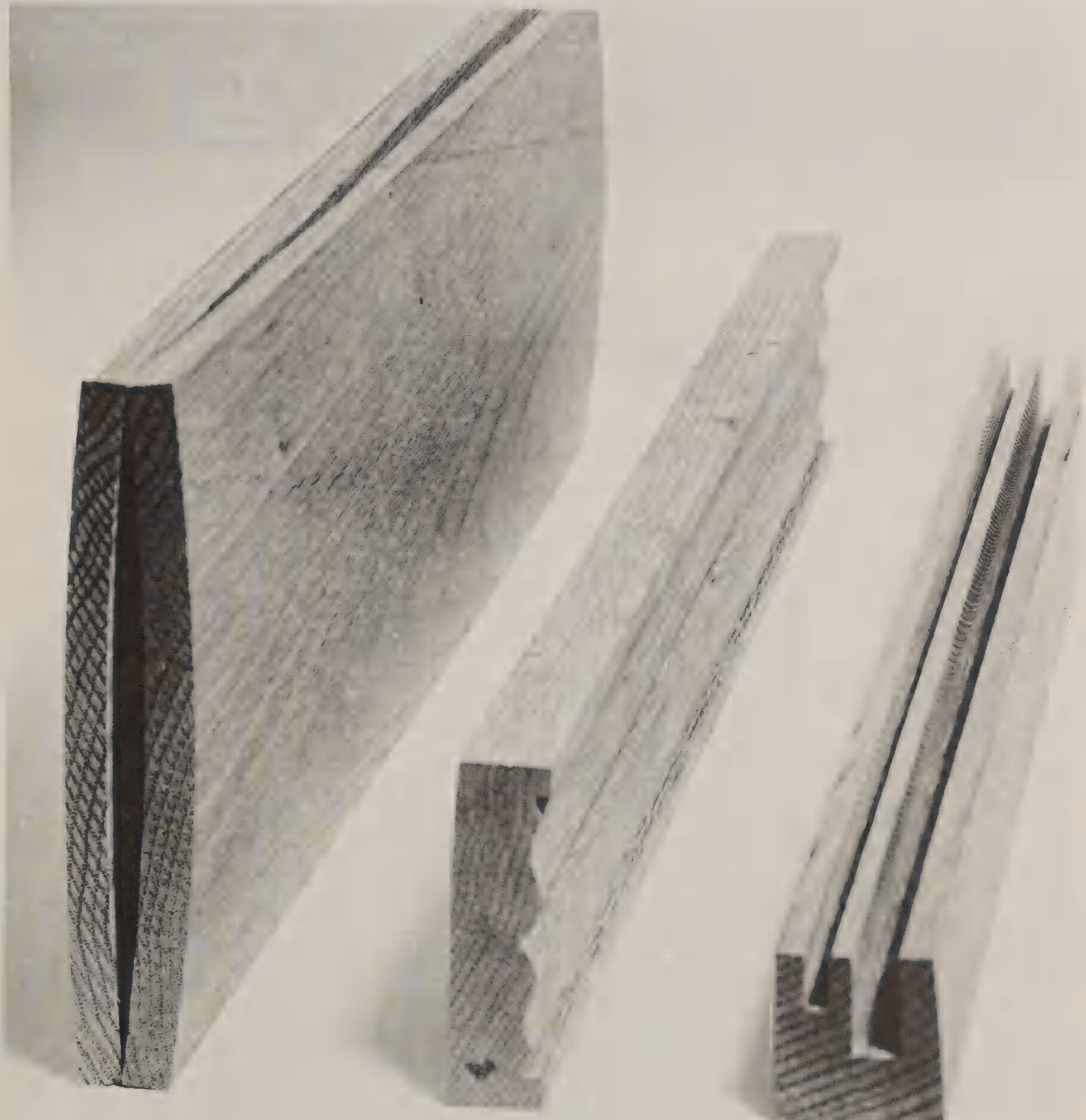

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Figure 8.—Stress revealed as immediate warp in resawn and molded items. USDA For. Serv., Agric. Handb. 188.

(1) The conditioning temperature is the same as the final step of the drying schedule or the highest temperature at which the conditioning equilibrium moisture content (EMC) can be controlled. For softwoods, set the wet-bulb temperature so the conditioning EMC will be 3 percent above the desired final average moisture content. For hardwoods, the conditioning EMC is 4 percent above the desired final average moisture content. The wet-bulb depression that will give the desired conditioning EMC is obtained from Table 1. If at the desired conditioning temperature, a wet-bulb depression value is not shown for the desired EMC, choose the wet-bulb depression value for the nearest higher EMC given for that temperature.

Table 1.—Relative humidity[1] and equilibrium[2] moisture content values occurring at various dry-bulb temperatures and wet-bulb depressions. USDA For. Serv., Agric. Handb. 188.

Temperature dry bulb (°F.)	Wet-bulb depression (°F.)																																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	32	34	36	38	40	45	50
30	89	78	67	57	46	36	27	17	6	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	---	*15.9*	*12.9*	*10.8*	*9.0*	*7.4*	*5.7*	*3.9*	*1.6*	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
35	90	81	72	63	54	45	37	28	19	11	3	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	---	*16.8*	*13.9*	*11.9*	*10.3*	*8.8*	*7.4*	*6.0*	*4.5*	*2.9*	*0.8*	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
40	[illegible]	83	75	68	60	52	45	37	29	22	15	8	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	---	*17.6*	*14.8*	*12.9*	*11.2*	*9.9*	*8.6*	*7.4*	*6.2*	*5.0*	*3.5*	*1.9*	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
45	93	85	78	72	64	58	51	44	37	31	25	19	12	6	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	---	*18.3*	*15.6*	*13.7*	*12.0*	*10.7*	*9.5*	*8.5*	*7.5*	*6.5*	*5.3*	*4.2*	*2.9*	*1.5*	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
50	93	86	80	74	68	[illegible]	56	50	44	38	32	27	21	16	10	5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	---	*19.0*	*16.3*	*14.4*	*12.7*	*11.5*	*10.3*	*9.4*	*8.5*	*7.6*	*6.7*	*5.7*	*4.8*	*3.9*	*2.8*	*1.5*	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
55	94	88	82	76	70	65	60	54	49	44	39	34	28	24	19	14	9	5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	---	*19.5*	*16.9*	*15.1*	*13.4*	*12.2*	*11.0*	*10.1*	*9.3*	*8.4*	*7.6*	*6.8*	*6.0*	*5.3*	*4.5*	*3.6*	*2.5*	*1.3*	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	---	*19.9*	*17.4*	*15.6*	*13.9*	*12.7*	*11.6*	*10.7*	*9.9*	*9.1*	*8.3*	*7.6*	*6.9*	*6.3*	*5.6*	*4.9*	*4.1*	*3.2*	*2.3*	*1.3*	*0.2*	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
65	95	90	84	80	75	70	66	61	56	52	48	44	39	36	32	27	24	20	16	13	8	6	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	---	*20.3*	*17.8*	*16.1*	*14.4*	*13.3*	*12.1*	*11.2*	*10.4*	*9.7*	*8.9*	*8.3*	*7.7*	*7.1*	*6.5*	*5.8*	*5.2*	*4.5*	*3.8*	*3.0*	*2.3*	*1.4*	*0.4*	----	----	----	----	----	----	----	----	----	----	----	----	----	----
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6	3	----	----	----	----	----	----	----	----	----	----	----	----
	---	*20.6*	*18.2*	*16.5*	*14.9*	*13.7*	*12.5*	*11.6*	*10.9*	*10.1*	*9.4*	*8.8*	*8.3*	*7.7*	*7.2*	*6.6*	*6.0*	*5.5*	*4.9*	*4.3*	*3.7*	*2.9*	*2.3*	*1.5*	*0.7*	----	----	----	----	----	----	----	----	----	----	----	----
75	[illegible]	91	86	82	78	74	70	66	62	58	54	51	47	44	41	37	34	31	28	24	21	18	15	12	10	7	4	1	----	----	----	----	----	----	----	----	----
	---	*20.9*	*18.5*	*16.8*	*15.2*	*14.0*	*12.9*	*12.0*	*11.2*	*10.5*	*9.8*	*9.3*	*8.7*	*8.2*	*7.7*	*7.2*	*6.7*	*6.2*	*5.6*	*5.1*	*4.7*	*4.1*	*3.5*	*2.9*	*2.3*	*1.7*	*0.9*	*0.2*	----	----	----	----	----	----	----	----	----
80	96	91	87	[illegible]	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	15	12	10	7	5	3	----	----	----	----	----	----	----
	---	*21.0*	*18.7*	*17.0*	*15.5*	*14.3*	*13.2*	*12.3*	*11.5*	*10.9*	*10.1*	*9.7*	*9.1*	*8.6*	*8.1*	*7.7*	*7.2*	*6.8*	*6.3*	*5.8*	*5.4*	*5.0*	*4.5*	*4.0*	*3.5*	*3.0*	*2.4*	*1.8*	*1.1*	*0.3*	----	----	----	----	----	----	----
85	96	92	88	84	80	76	73	70	66	[illegible]	59	56	53	50	47	44	41	38	36	33	30	28	25	23	20	18	15	13	11	9	4	----	----	----	----	----	----
	---	*21.2*	*18.8*	*17.2*	*15.7*	*14.5*	*13.5*	*12.5*	*11.8*	*11.2*	*10.5*	*10.0*	*9.5*	*9.0*	*8.5*	*8.1*	*7.6*	*7.2*	*6.7*	*6.3*	*6.0*	*5.6*	*5.2*	*4.8*	*4.3*	*3.9*	*3.4*	*3.0*	*2.4*	*1.7*	*0.9*	----	----	----	----	----	----
90	96	92	89	[illegible]	81	78	74	71	68	[illegible]	61	58	55	52	49	47	44	41	39	36	34	31	29	26	24	22	19	17	15	13	9	5	1	----	----	----	----
	---	*21.3*	*18.9*	*17.3*	*15.9*	*14.7*	*13.7*	*12.8*	*12.0*	*11.4*	*10.7*	*10.2*	*9.7*	*9.3*	*8.8*	*8.4*	*8.0*	*7.6*	*7.2*	*6.8*	*6.5*	*6.1*	*5.7*	*5.3*	*4.9*	*4.6*	*4.2*	*3.8*	*3.3*	*2.8*	*2.1*	*1.3*	*0.4*	----	----	----	----
95	96	[illegible]	89	85	82	79	75	72	69	66	63	60	57	55	52	49	46	44	42	39	37	34	32	30	28	26	23	22	20	17	14	10	6	2	----	----	----
	---	*21.3*	*19.0*	*17.4*	*16.1*	*14.9*	*13.9*	*12.9*	*12.2*	*11.6*	*11.0*	*10.5*	*10.0*	*9.5*	*9.1*	*8.7*	*8.2*	*7.9*	*7.5*	*7.1*	*6.8*	*6.4*	*6.1*	*5.7*	*5.3*	*5.1*	*4.8*	*4.4*	*4.0*	*3.6*	*3.0*	*2.3*	*1.5*	*0.6*	----	----	----
100	96	93	89	86	83	80	77	73	70	[illegible]	65	62	59	56	54	51	49	46	44	41	39	37	35	33	30	28	26	24	22	21	17	13	10	7	4	----	----
	---	*21.3*	*19.0*	*17.5*	*16.1*	*15.0*	*13.9*	*13.1*	*12.4*	*11.8*	*11.2*	*10.6*	*10.1*	*9.6*	*9.2*	*8.9*	*8.5*	*8.1*	*7.8*	*7.4*	*7.0*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5.2*	*4.9*	*4.6*	*4.2*	*3.6*	*3.1*	*2.4*	*1.6*	*0.7*	----	----
105	96	93	90	87	83	80	77	74	71	[illegible]	66	63	60	58	55	53	50	48	46	44	42	40	37	35	34	31	29	28	26	24	20	17	14	11	8	----	----
	---	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.0*	*13.2*	*12.6*	*11.9*	*11.3*	*10.8*	*10.3*	*9.8*	*9.4*	*9.0*	*8.7*	*8.3*	*7.9*	*7.6*	*7.3*	*6.9*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.2*	*3.6*	*3.1*	*2.4*	*1.8*	----	----
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	44	42	40	38	36	34	32	30	28	26	23	20	17	14	11	4	----
	---	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.3*	*12.6*	*12.0*	*11.4*	*10.8*	*10.4*	*9.9*	*9.5*	*9.2*	*8.8*	*8.4*	*8.1*	*7.7*	*7.5*	*7.2*	*6.8*	*6.6*	*6.3*	*6.0*	*5.7*	*5.4*	*5.2*	*4.8*	*4.5*	*4.0*	*3.5*	*3.0*	*2.5*	*1.1*	----
115	97	93	90	88	85	82	79	76	74	71	68	66	63	61	58	56	54	52	50	48	45	43	41	40	38	36	34	32	31	29	26	23	20	17	14	8	2
	---	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.4*	*12.7*	*12.1*	*11.5*	*10.9*	*10.4*	*10.0*	*9.6*	*9.3*	*8.9*	*8.6*	*8.2*	*7.8*	*7.6*	*7.3*	*7.0*	*6.7*	*6.5*	*6.2*	*5.9*	*5.6*	*5.4*	*5.2*	*4.7*	*4.3*	*3.9*	*3.4*	*2.9*	*1.7*	*0.4*
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53	51	49	47	45	43	41	40	38	36	34	33	31	28	25	22	19	17	10	5
	---	*21.3*	*19.0*	*17.4*	*16.2*	*15.1*	*14.1*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*	*8.3*	*7.9*	*7.7*	*7.4*	*7.2*	*6.8*	*6.6*	*6.3*	*6.1*	*5.8*	*5.6*	*5.4*	*5.0*	*4.6*	*4.2*	*3.7*	*3.3*	*2.3*	*1.1*
125	97	94	91	88	86	[illegible]	80	77	75	73	70	68	65	63	61	59	57	55	53	51	48	47	45	43	41	39	38	36	35	33	30	27	24	22	19	13	8
	---	*21.2*	*18.9*	*17.3*	*16.1*	*15.0*	*14.0*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*	*8.3*	*8.0*	*7.7*	*7.5*	*7.2*	*7.0*	*6.7*	*6.5*	*6.2*	*6.0*	*5.8*	*5.5*	*5.2*	*4.8*	*4.4*	*4.0*	*3.6*	*2.7*	*1.6*
130	97	[illegible]	91	89	86	83	81	78	76	73	71	69	67	64	62	60	58	56	54	52	50	48	47	45	43	41	40	38	37	35	32	29	26	24	21	15	10
	---	*21.0*	*18.8*	*17.2*	*16.0*	*14.9*	*14.0*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*	*8.3*	*8.0*	*7.8*	*7.6*	*7.3*	*7.0*	*6.8*	*6.6*	*6.4*	*6.1*	*5.9*	*5.6*	*5.3*	*4.9*	*4.6*	*4.2*	*3.8*	*3.0*	*2.0*
140	97	95	92	89	87	84	[illegible]	79	77	75	73	70	68	66	64	62	60	58	56	54	53	51	49	47	46	44	43	41	40	38	35	32	30	27	25	19	14
	---	*20.7*	*18.6*	*16.9*	*15.8*	*14.8*	*13.8*	*13.2*	*12.5*	*11.9*	*11.4*	*10.9*	*10.4*	*10.0*	*9.6*	*9.4*	*9.0*	*8.7*	*8.4*	*8.0*	*7.8*	*7.6*	*7.3*	*7.1*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.1*	*4.8*	*4.4*	*4.1*	*3.4*	*2.6*
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66	64	62	60	58	57	55	53	51	49	48	46	45	43	42	41	38	36	33	30	28	23	18
	---	*20.2*	*18.4*	*16.6*	*15.4*	*14.5*	*13.7*	*13.0*	*12.4*	*11.8*	*11.2*	*10.8*	*10.3*	*9.9*	*9.5*	*9.2*	*8.9*	*8.6*	*8.3*	*8.0*	*7.8*	*7.5*	*7.3*	*7.1*	*6.9*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.2*	*4.9*	*4.5*	*4.2*	*3.6*	*2.9*
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	57	55	53	52	50	49	47	46	44	43	41	38	35	33	31	25	21
	---	*19.8*	*18.1*	*16.2*	*15.2*	*14.2*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.6*	*10.1*	*9.7*	*9.4*	*9.1*	*8.8*	*8.5*	*8.2*	*7.9*	*7.7*	*7.4*	*7.2*	*7.0*	*6.8*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.5*	*5.2*	*4.9*	*4.6*	*4.3*	*3.7*	*3.2*
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	63	62	60	59	57	55	53	52	51	49	48	47	45	43	40	38	35	[illegible]	28	24
	---	*19.4*	*17.7*	*15.8*	*14.8*	*13.9*	*13.2*	*12.4*	*11.8*	*11.3*	*10.8*	*10.4*	*9.9*	*9.6*	*9.2*	*9.0*	*8.6*	*8.4*	*8.0*	*7.8*	*7.6*	*7.3*	*7.2*	*6.9*	*6.7*	*6.6*	*6.4*	*6.2*	*6.0*	*5.7*	*5.5*	*5.2*	*4.9*	*4.6*	*4.4*	*3.7*	*3.2*
180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65	63	62	60	58	57	55	54	52	51	50	48	47	45	42	40	38	35	30	26
	---	*18.9*	*17.3*	*15.5*	*14.5*	*13.7*	*12.9*	*12.2*	*11.6*	*11.1*	*10.6*	*10.1*	*9.7*	*9.4*	*9.0*	*8.8*	*8.4*	*8.1*	*7.8*	*7.6*	*7.4*	*7.2*	*7.0*	*6.8*	*6.5*	*6.4*	*6.2*	*6.0*	*5.8*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.4*	*3.8*	*3.3*
190	98	96	94	92	90	88	85	84	82	80	78	76	75	73	71	69	68	66	65	63	62	60	58	57	56	54	53	51	50	49	46	44	42	39	37	32	28
	---	*18.5*	*16.9*	*15.2*	*14.2*	*13.4*	*12.7*	*12.0*	*11.4*	*10.9*	*10.5*	*10.0*	*9.6*	*9.2*	*8.9*	*8.6*	*8.2*	*7.9*	*7.7*	*7.4*	*7.2*	*7.0*	*6.8*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.5*	*5.3*	*5.0*	*4.8*	*4.5*	*4.4*	*3.8*	*3.3*
200	98	96	94	92	90	88	86	84	82	80	79	77	75	74	72	70	69	67	66	64	63	61	60	58	57	55	54	53	52	51	48	46	43	41	39	34	30
	---	*18.1*	*16.4*	*14.9*	*14.0*	*13.2*	*12.4*	*11.8*	*11.2*	*10.8*	*10.3*	*9.8*	*9.4*	*9.1*	*8.8*	*8.4*	*8.1*	*7.7*	*7.5*	*7.2*	*7.0*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.6*	*5.4*	*5.2*	*4.9*	*4.7*	*4.5*	*4.3*	*3.8*	*3.3*
210	98	96	[illegible]	[illegible]	90	88	86	85	83	81	79	78	76	75	73	71	70	68	67	[illegible]	64	63	61	60	59	57	56	54	53	52	50	47	45	43	41	36	32
	---	*17.7*	*16.0*	*14.6*	*13.8*	*13.0*	*12.2*	*11.7*	*11.1*	*10.6*	*10.0*	*9.7*	*9.2*	*9.0*	*8.7*	*8.3*	*8.0*	*7.6*	*7.4*	*7.1*	*6.9*	*6.8*	*6.5*	*6.3*	*6.1*	*5.9*	*5.8*	*5.5*	*5.4*	*5.3*	*5.1*	*4.8*	*4.6*	*4.4*	*4.2*	*3.7*	*3.2*

[1] Relative-humidity values in roman type.
[2] Equilibrium-moisture-content values in italic type.

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Example: Assume a hardwood, a final desired moisture content of 8 percent, and a conditioning temperature of 170° F. The conditioning EMC from Table 2 is 12 percent. At 170°, an 8° wet-bulb depression will give an EMC of 12.4 percent (Table 1). If the material were a softwood, the conditioning EMC would be 11 percent and the wet-bulb depression 10°.

(2) Continue conditioning until satisfactory stress relief is attained.

The time required for conditioning varies considerably, depending upon species and thickness of the lumber, the type of kiln used, and kiln performance. Hardwoods generally require 16 to 24 hours for 4/4 stock, and up to 48 hours for 8/4. The 4/4 thickness of some softwood species can be conditioned in as little as 4 hours.

Table 2.— Kiln sample moisture content and equilibrium moisture content values for equalizing and conditioning a charge of lumber. USDA For. Serv., Agric. Handb. 188.

	Equalizing			Conditioning equilibrium moisture content values	
Desired final average moisture content	Moisture content of driest sample at start	Equilibrium moisture content during this step	Moisture content of wettest sample at end	For softwoods	For hardwoods
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
5	3	3	5	8	9
6	4	4	6	9	10
7	5	5	7	10	11
8	6	6	8	11	12
9	7	7	9	12	13
10	8	8	10	13	14
11	9	9	11	14	15

VI. Stain

A. Causes

Stain, if regarded as a defect, can be quantified by DQA in terms of its influence on the yield of cut parts if the bounds of the stained area are definable. Stain may be caused by such diverse agents as microorganisms, metal, or chemicals.

B. Visual Recognition

The following are common stains:

(1) Blue stain, or sap stain, is caused by a dark colored fungus on the surface or interior of sapwood. Its growth is made possible by the presence of food, moisture, and air under favorable temperature conditions. It grows most rapidly in wood at a moisture content of 20 percent or more and a temperature of 75 to 85° F.

(2) Chemical brown stain, or coffee stain, may occur in yard or kiln drying and is believed to be caused by a concentration and modification of extractives. High humidity, warm days, and low air circulation encourage it. It occurs frequently on eastern white pine during the summer months.

(3) Sticker stain is the discoloration that sometimes occurs where stickers contact the lumber. It is caused by a fungus, and wet stickers encourage it.

(4) Pink stain on white woods, particularly maple and ash, results from redistribution of brown deposits in the rays under conditions of high humidity, warm temperature, and low air circulation.

(5) Iron stain on oak appears black and is traceable to iron coming in contact with the wood surface.

C. Prevention

Fungal growth can be prevented on lumber and other products by rapidly drying the surfaces to 20% or less moisture content and keeping them dry. To accomplish this requires sticking the lumber as soon as it is sawn. If this is impossible, toxic chemicals can be used to retard the growth of fungi until the lumber can be put up on stickers. For the names of companies that manufacture chemicals for dipping lumber, consult any industrial directory under "Insecticides." Observe all the precautions on the label when using such products.

Chemical stains can be prevented by rapid drying at low temperature. If the stain originated in the logs, the logs remained in the woods too long. The corrective action is to move logs to the mill immediately when conditions favor stain development and stick the lumber promptly after sawing.

VII. DQA Computer Logic

Tables 3 and 4 show the influence of bow and cup on the yield of cut parts; these relationships are part of the DQA computer logic.

Table 3.— Maximum length cuttings in inches from 26/32" thick, rough dry 1" lumber when bow is a factor

Board length, inches	Amount of bow, inches 0.0	0.2	0.4	0.6	0.8	1.0	2.0
100	100	79	56	46	40	35	25
150	150	119	84	69	59	53	38
200	200	160	112	91	79	71	50

Table 4.— Maximum width cuttings in inches from 26/32" thick, rough dry 1" lumber when cup is a factor

Board width, inches	Amount of cup, inches 0.0	0.2	0.4	0.6	0.8	1.0
4	4.0	3.3	2.5	2.1	2.0	1.9
6	6.0	4.9	3.5	3.0	2.6	2.4
8	8.0	6.4	4.6	3.8	3.4	3.1

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